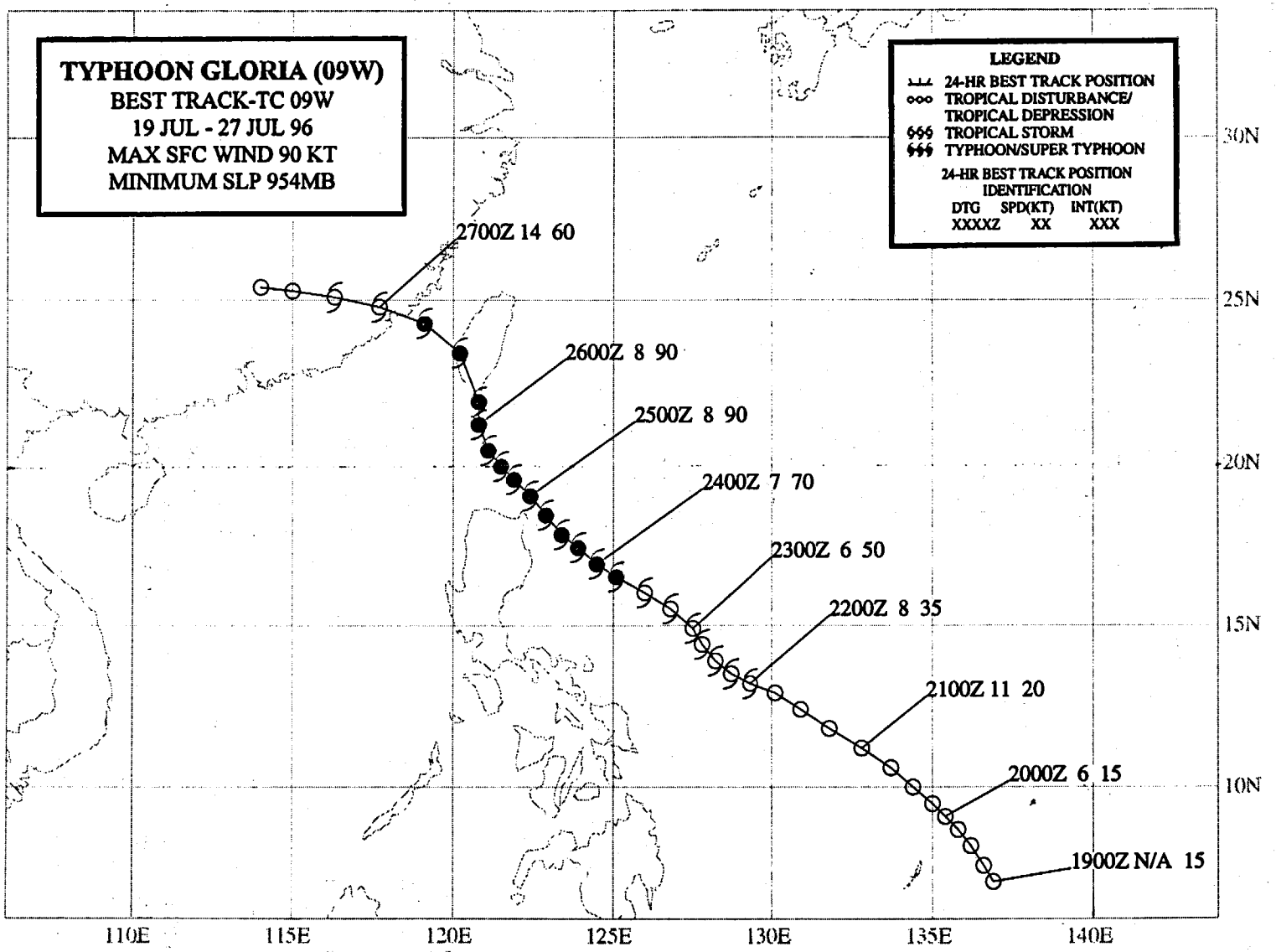
TYPHOON GLORIA (09W)
BEST TRACK-TC 09W
19 JUL - 27 JUL 96
MAX SFC WIND 90 KT
MINIMUM SLP 954MB
LEGEND
24-HR BEST TRACK POSITION
TROPICAL DISTURBANCE/ TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON/SUPER TYPHOON
24-HR BEST TRACK POSITION IDENTIFICATION
DTG SPD(KT) INT(KT)
XXXXZ XX XXX
2700Z 14 60
2600Z 8 90
2500Z 8 90
2400Z 7 70
2300Z 6 50
2200Z 8 35
2100Z 11 20
2000Z 6 15
1900Z N/A 15
30N
25N
20N
15N
10N
110E
115E
120E
125E
130E
135E
140E

TYPHOON GLORIA (09W)

I. HIGHLIGHTS

Developing from a monsoon depression in the Philippine Sea, Gloria moved northwestward, became a typhoon, and affected Luzon, Taiwan, and eastern China. During the early phases of its development, Gloria formed a very large Central Cold Cover (CCC) with a near-record cloud-top temperature of -100°C.

II. TRACK AND INTENSITY

During the latter half of July, extensive amounts of deep convection formed in an east-west band extending across the WNP from the coast of Southeast Asia to the Marshall Islands. By 21 July, this cloud band had consolidated into three distinct cloud clusters (see Figure 3-10-1 in Herb's (10W) summary), all of which became named tropical cyclones — from west to east: Frankie (08W), Gloria, and Herb (10W). The tropical disturbance which became Gloria was first mentioned on the 170600Z July Significant Tropical Weather Advisory when synoptic data from Koror (WMO 91408) indicated the presence of a weak cyclonic circulation associated with a region of enhanced deep convection along the monsoon trough. Over the course of the next few days this disturbance moved slowly westward without much sign of increased organization in the deep convection or the surface wind field.

Early on 21 July, convection in the pre-Gloria disturbance became more organized and the first of two Tropical Cyclone Formation Alerts (TCFA) was issued valid at 201830Z. The areal extent of deep convection in this disturbance increased markedly, and the system acquired the structure of a monsoon depression. Although the cloud system appeared to be well organized, synoptic data still indicated that the winds were weak, and most of the deep convection had not yet consolidated near the low-level circulation center (LLCC). Thus, a second TCFA was issued valid at 211830Z, containing a caution stating deep convection had begun to develop near the LLCC (Figure 3-09-1), and formation of a significant tropical cyclone was anticipated within 6 to 12 hours. Indeed, when synoptic reports were received which indicated the wind speed had reached 30 kt (15 m/sec) in the broad circulation, the first warning on Tropical Depression 09W was issued valid at 220000Z. Steering flow was dominated by a strong subtropical ridge to its north, and Gloria was forecast to move on a steady west-northwest track towards Luzon.

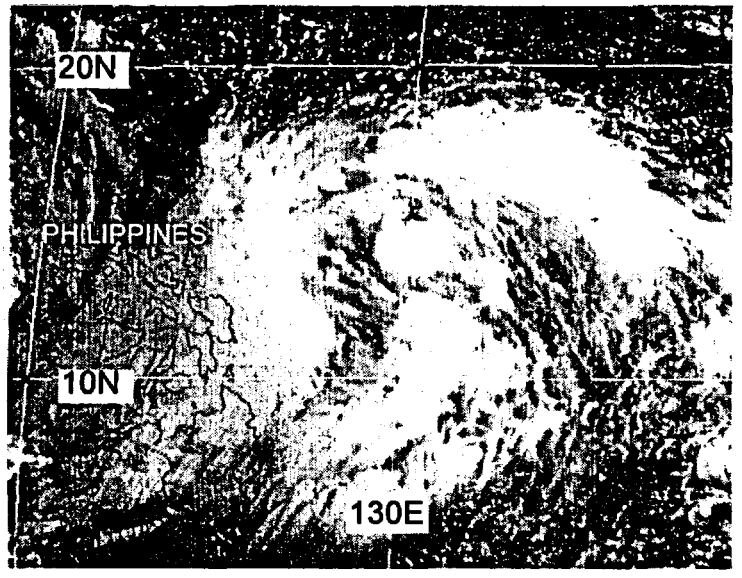

Figure 3-09-1 The mesoscale convective systems within the pre-Gloria monsoon depression show signs of increased organization and consolidation toward the LLCC, prompting the first warning (212224Z July visible GMS imagery).

Based upon synoptic reports of gales within the large circulation, TD 09W was upgraded to Tropical Storm Gloria on the warning valid at 221200Z. During the night, following its upgrade to tropical-storm intensity, and subsequent increase to 55 kt (28 m/sec), Gloria underwent a profound structural change: a very large Central Cold Cover (CCC) formed (see the discussion section). This CCC persisted from the late evening of 23 July to the morning of 24 July. As the CCC began to dissipate, Gloria became a typhoon. By the afternoon of 24 July, the cirrus debris of the CCC had largely cleared away revealing that Gloria had acquired a visible eye.

Tracking on a more northwestward course than forecast, Gloria brushed by Luzon and entered the Luzon Strait. It is here, during the afternoon of 26 August that Gloria made an abrupt jog to the north to make landfall on the southern tip of Taiwan. The typhoon then made a quick jump to the western coast of Taiwan, where it then turned to the west, crossed the Taiwan Strait and went inland in southeastern China. The peak intensity of 90 kt (46 m/sec) was maintained from 241200Z to 260600Z as Gloria moved across the Luzon Strait and made landfall in Taiwan. After landfall in Taiwan, its intensity dropped to the typhoon threshold, and having little time to recover during its passage across the Taiwan Strait, it entered mainland China as a minimal typhoon and quickly dissipated over land. The final warning was issued at 270600Z.

III. DISCUSSION

a. *An unusually large Central Cold Cover*

Dvorak (1984) noted that the use of enhanced IR imagery required the introduction of a new concept — the central cold cover (CCC) — in order to deal with the occurrence of a sudden spreading of cold clouds over the central features of a TC. When a CCC persists, it signals an interruption in the development of the TC. Specific details of the CCC pattern are found in Dvorak (1984):

"The CCC pattern is defined when a more or less round, cold overcast mass of clouds covers the storm center or comma head obscuring the expected signs of pattern evolution. The outer curved bands and lines usually weaken with the onset of CCC. When using VIS pictures, substitute the word 'dense' for 'cold'. It is only rarely that the CCC pattern is used with VIS pictures since the CDO [central dense overcast] or curved lines are usually visible through the thin cirrus clouds. When the CCC persists . . . , development has been arrested until signs of development or weakening once again appear in the cloud features. Care should be exercised under the following conditions:

"1) Do not confuse a CCC pattern with a very cold comma pattern. A very cold (usually white [i.e., a gray-shade enhancement on the BD curve that is indicative of temperatures between -70 to -75°C]) pattern is indicated by a very cold (very smooth texture) comma tail and head with some indication of a wedge in between. Curved cirrus lines or boundaries usually appear around the [very] cold [comma] pattern and not around the CCC pattern. The very cold [comma] pattern for T-numbers of T3 or less warrant an additional 1/2 number in intensity estimate and often indicates rapid growth.

"2) Do not assume weakening in a CCC pattern when the comma tail begins to decrease in size. It is common to observe the tail decreasing in size at the onset of the CCC. Also, the CCC often warms as the eye of the T4 pattern begins to be carved out by a warm incursion into the side of the cold overcast. This signals the resumption of pattern evolution (intensification) even though some warming is evident."

In the WNP, the CCC pattern is observed every year in the developmental process of several of the named TCs. One major difference between the CCC pattern observed in the WNP versus the North Atlantic (where Dvorak obtained most of the data for the development of his techniques) is that the cloud-top temperature of the CCC tends to be at least 10°C to 15°C colder in the WNP. Another difference between the CCC patterns observed in the WNP versus those observed in the Atlantic is the very large size of some of the CCC patterns observed in the WNP.

Prior to the formation of its CCC, Gloria had been developing as a monsoon depression. During the evening hours of 23 July, a cluster of small cold-topped MCSs began to grow near the estimated center position of Gloria. During a six-hour period, this cluster of MCSs mushroomed into an enormous CCC (Figure 3-09-2a-e). By local midnight, the average diameter of the area within which the cloud-top temperature was at or below -70°C was approximately 700 km (Figure 3-09-3). Roughly half of this area was colder than -90°C. The coldest IR pixel, with an equivalent black-body temperature of -100°C, was located near the geometric center of the CCC. This is an extremely cold cloud-top temperature which is rarely seen. It is only 2°C shy of the record cold cloud-top temperature of -102°C reported by Ebert and Holland (1992) in the deep convection associated with a TC near Australia.

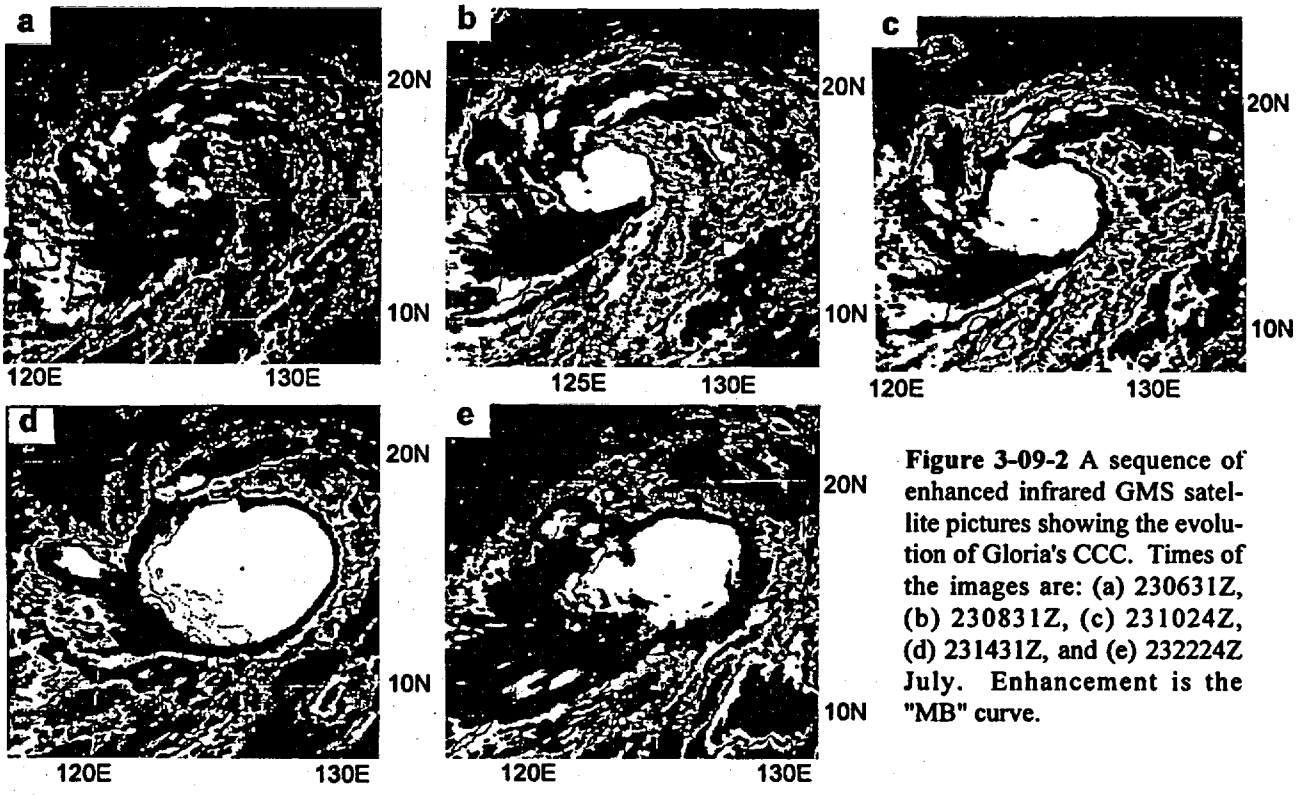

Figure 3-09-2 A sequence of enhanced infrared GMS satellite pictures showing the evolution of Gloria's CCC. Times of the images are: (a) 230631Z, (b) 230831Z, (c) 231024Z, (d) 231431Z, and (e) 232224Z July. Enhancement is the "MB" curve.

By the early daylight hours of 24 July, the periphery of the CCC began to warm on IR imagery, and a new smaller CCC mushroomed into the preexisting cold cirrus canopy (Figure 3-09-4). As the day progressed, the underlying structure of Gloria gradually emerged in VIS imagery as the supporting convection of the CCC ended, and the large cirrus canopy of the CCC thinned. By mid-afternoon, the cold cirrus of the CCC became nearly transparent, and the eye, wall cloud, and peripheral convective cloud bands of the intensifying Gloria were then plainly seen (Figure 3-09-5).

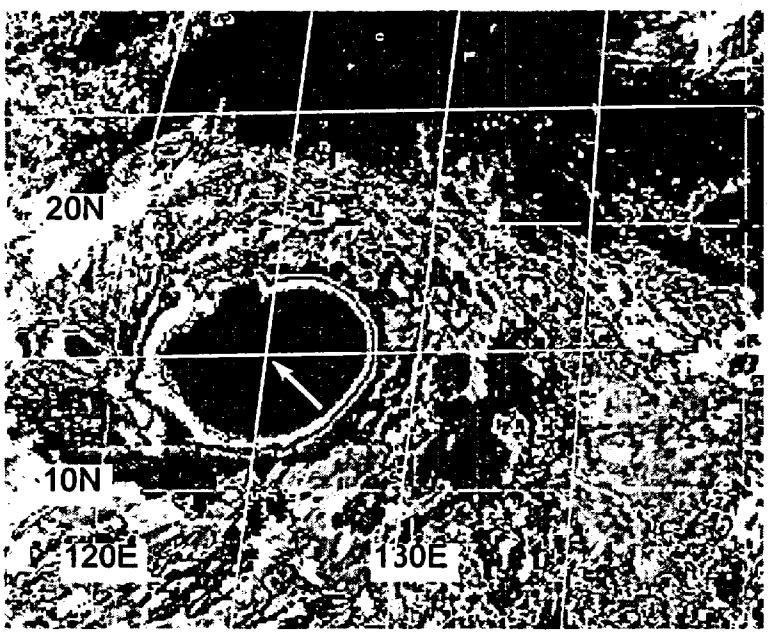

Figure 3-09-3 Gloria's CCC reaches its maximum areal extent, and registers its coldest temperatures. The location of the coldest temperature of -100°C is indicated by the arrow. Enhancement is the basic Dvorak, or "BD", curve applied to the 231431Z July infrared GMS imagery.

In the 24-hour period encompassing the full evolution of Gloria's CCC, the estimated intensity increased from 55 kt to 75 kt; hardly a remarkable change considering the extreme changes in the cloud pattern. This is consistent with Dvorak's findings that the appearance of a CCC signals arrested (or at least slowed) development which is renewed as the eye pattern of the T4 (minimal typhoon intensity) emerges beneath the thinning cirrus. Additional observations made during the occurrence of the CCC pattern in WNP TCs include the following:

1) the CCC usually begins to form at local sunset (this is at some variance with observations by Black and collaborators (e.g., Black, 1983; Black, et al., 1986; Black and Marks, 1987) who

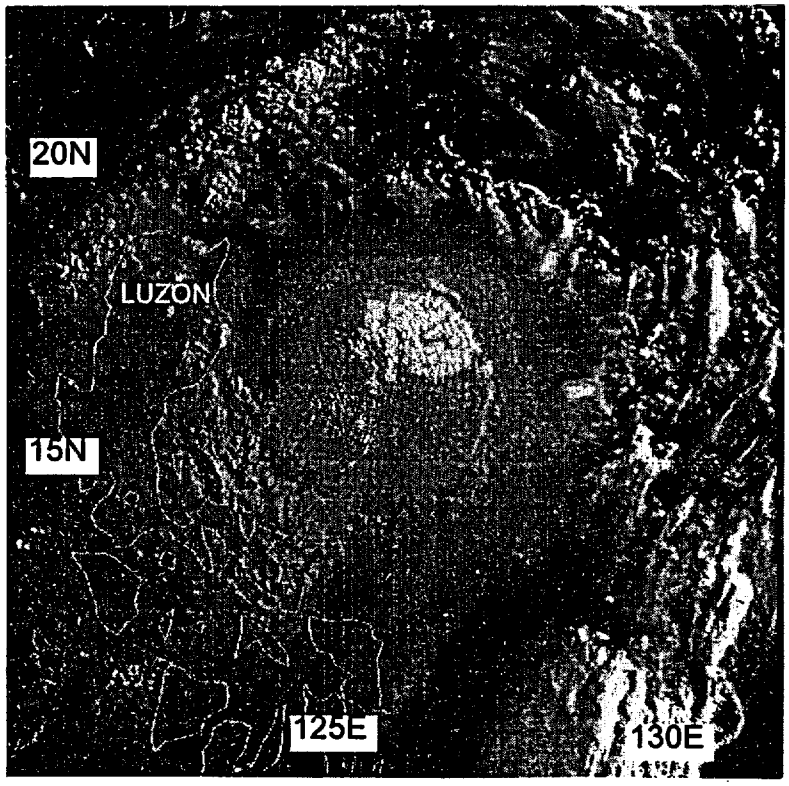

Figure 3-09-4 The appearance of Gloria's CCC by the early local daylight hours of 24 July: another pulse of dense cirrus is mushrooming into the thinning remains of earlier cold cirrus (232224Z July visible GMS imagery).

show that major cold convective eruptions in TCs tend to be initiated in the early morning);

2) the CCC reaches its greatest size and coldest temperature between local midnight and predawn; and,

3) the CCC pattern is most commonly observed to occur in weaker TCs that are at intensities of between T3 to T4 (45 - 65 kt) (this is consistent with observations of the aforementioned Black and collaborators; it is not consistent with guidance in Dvorak's 1984 report wherein it is stated that the CCC could occur at any stage of development of the TC and last for several hours to several days).

b. *The influence of Taiwan on the motion of tropical cyclones*

As Gloria was moving slowly to the northwest in the Luzon Strait, it made an abrupt turn to the north, and made landfall on the extreme southern tip of Taiwan. It then made an abrupt jump to the west coast of Taiwan before resuming a westward track toward mainland China. It is offered as a hypothesis that this abrupt meander in Gloria's track was induced by the island of Taiwan. Research by the Taiwan Central Weather Bureau (CWB) (1982) has demonstrated that the island of Taiwan can significantly alter the tracks of typhoons that approach it. The effects differ depending upon the angle of approach. The track changes noted during Gloria's approach to Taiwan are consistent with the track changes noted by the CWB which occur when a typhoon approaches Taiwan from the south or southeast.

IV. IMPACT

In the Philippines, Gloria was reported to have killed at least 20 people and caused nearly US $40 million in property damage. Hardest hit were the northeastern provinces of Luzon, where the eye of Gloria approached to within 60 nm (110 km) of the northeastern tip of the island. Gloria also passed to within 60 nm (110 km) of some of the smaller islands in the Luzon Strait where, although there were reports of typhoon force winds, the JTWC received no reports of any damage or injuries. On Taiwan, three people were reported killed: a child by a falling tree, an adult as he was blown from his motorcycle into a creek, and another adult as he fell from a roof. Rock slides disrupted traffic along Taiwan's east coast, and heavy rains flooded fields and caused several rivers to overflow their banks.

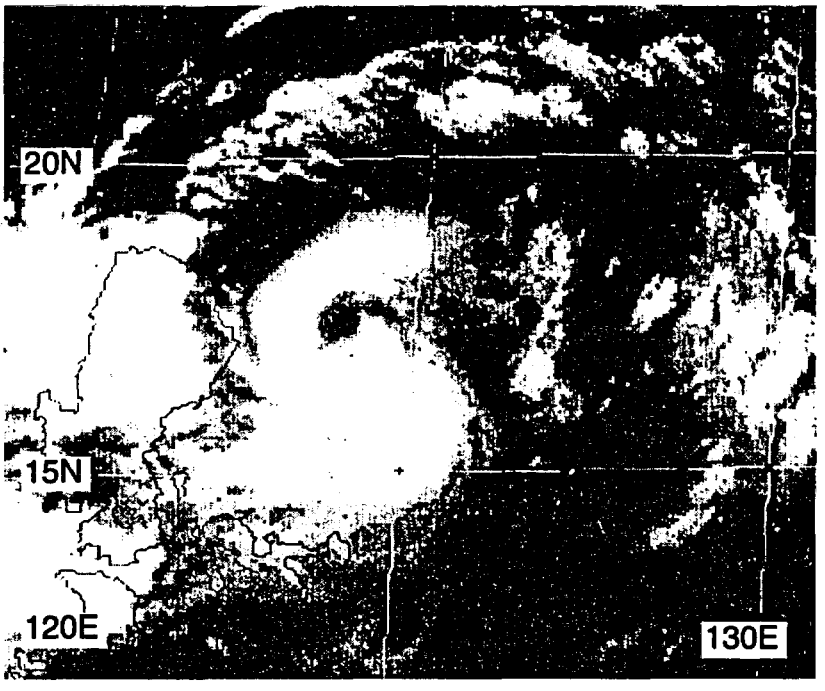

Figure 3-09-5 The eye, wall cloud, and peripheral rainbands of Gloria are plainly visible after the cirrus overcast of the CCC cleared away (240531Z visible GMS imagery).